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Sealing Depth of Q-Switched Nd:YAG 1064nm Laser in the Treatment of Patients with Hypersensitive Teeth: An In Vitro Study

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Abstract: The purpose of this work was to study the effects of the Nd:YAG laser on exposed dentinal tubules of human extracted teeth using a scanning electron microscope (SEM). Eighty 2.5mm-thick slices were cut at the cementoenamel junction from 20 extracted human teeth with an electric saw. A diamond bur was used to remove the cementum layer to expose the dentinal tubules. Each slice was sectioned into four equal quadrants and the specimens were randomly divided into four groups (A to D). Groups B to D were lased for 2 mins using an Nd:YAG laser at 6 pulses per second at energy outputs of 80 , 100 and 120 mJ. Group A served as control. Under SEM observation, nonlased specimens showed numerous exposed dentinal tubules. SEM observation revealed that application of Nd:YAG laser at energy output of 80 mJ may cause melting of dentin and partial closure of exposed dentinal tubules without dentin surface cracking. But when the energy output raised to 100 and 120 mJ more sealing of dentinal tubules occurs. Heat generation occurred in all lased groups but the amount of temperature increase was within the permissible limits(less than 5.5^0C). The measured sealing depths were from 3-5µm for groups B-D and the width of the created groove was 30µm in all lased groups. In conclusion lasing with nanosecond Nd:YAG with a wavelength of 1064nm at 120mJ with 6Hz for 2 minutes (group D) shows the efficient laser parameters for complete sealing of exposed dentinal tubules without temperature increase to the damaging level of the pulp tissue.

Introduction

Dentin Hypersensitivity (DH) is characterized by short sharp pain arising from exposed dentin in response to stimulitypically thermal, evaporative, tactile, osmotic and chemical that cannot be ascribed to any other dental defect or disease. Dentin Hypersensitivity usually is diagnosed after other possible conditions have been eliminated. Alternative causes of pain include chipped or fractured teeth, cracked cusps, carious lesions, leaky restorations and palatogingival grooves. The clinical features of DH are well documented (Robin and David, 2006).

Dentin Hypersensitivity affects one in seven adult patients, with no significant difference in prevalence between the sexes. Premolars have a larger incidence, and the cervical area of the buccal surface has a larger frequency of this disorder than other teeth (Ana Lucia, et al., 2003). Dentin Hypersensitivity It has a high prevalence rate among patients that are 30 to 45 years old, and it occurs even among patients with outstanding oral hygiene. There are several reports on how healthy teeth or the presence of a gingival retraction or small abrasion predispose this condition. Several authors believe that the presence of inter-dentinal nervous fibers (18.000 to 40.000 tubes per mm^2) which are exposed to the oral environment and susceptible to local stimuli is what causes the symptoms (Robin and David, 2006, Lucia, et al., 2003; Brugnera, 2004). In response to questionnaires, dentists have reported that dentin hypersensitivity affects between 10 and 25 percent of their patients. Schuurs and colleagues also reported that dentists believe dentin hypersensitivity presents a severe problem for only 1 percent of their diagnosed patients (Robin and David, 2006, Lucia, et al., 2003, Brugnera, 2004, Schuurs, et al., 1996). Theories about the transmission of pain stimuli in dentin sensitivity suggest that pain is amplified when the dentinal tubules are open to the oral cavity. Therefore dentin hypersensitivity can be a major problem for periodontal patients, who frequently have gingival recession and exposed root surfaces (Heodor, 2006).

The conventional treatment for dentin hypersensitivity is by using desensitizing agents or by covering the exposed dentin area by using different types of restorations, while laser therapy involves the sealing of the exposed dentinal tubules by the thermal effect of the laser beam to reduce or even cease pain (Heodor, 2006). Several types of lasers are used in the treatment of dentin hypersensitivity. The effectiveness of lasers for treating dentin hypersensitivity varies from 5 to 100 percent, depending on the type of laser and the treatment parameters. Studies have reported that the neodymium:yttrium-aluminum-garnet (YAG) laser, the Erbium:YAG laser and galium-aluminium- arsenide low level laser all reduce dentin hypersensitivity, but the reductions were not significantly different from those of a placebo or positive controls. In addition to these equivocal results, lasers represent a more expensive and complex treatment modality (Robin and David, 2006).

Aims of the study

1- To determine the efficiency of Nd:YAG laser 1064 nm in sealing of exposed dentinal tubules.
2- To determine the surface characteristics of the lased dentinal tubules at different laser beam energies.
3- To measure the sealing depth of Nd:YAG laser for the lased dentinal tubules.
4- Measuring the temperature increase at different beam energies.

Materials and Methods

Twenty different sound teeth have been extracted and collected from 17 patients (age 16-50 years) with orthodontic and periodontic problems. The teeth were collected through a period of three months. The laser device has been used in this study was Nd:YAG Q-Switched pulsed laser device (Diamond beauty, China). This device emits three types of lasers: The first is a pilot diode laser emitting laser light at a wavelength of 655nm (red light) delivering maximum power of 1mW of continuous laser radiation with class II laser according to the (ANSI) classification in 1993. Its benefit is to visualize and direct the therapy laser beam on the target area. The second laser is the therapy laser, which is a solid state pulsed Nd:YAG laser emitting radiation at wavelength of 1064 nm in the infrared region of the electromagnetic spectrum (also called the fundamental beam), and classified as a class IV laser according to the (ANSI) classification in 1993 and is supplied with its protective eyewear. The third laser can be obtained by attaching a KTP crystal to the laser gun to get a green laser with 532nm wavelength (also called the second harmonic beam), and classified as a class IV laser according to the (ANSI) classification in 1993 and is supplied with its protective eyewear. The pulses energy of the therapeutic Nd:YAG laser are from 20-1000mJ. It is adjustable in the range of 20 mJ steps. The PRR is also adjustable from 1-6 Hz and the pulse duration is 9ns in the fundamental beam and 6ns in the second harmonic beam. Non-contact IR thermometer (model AR842, SMART SENSOR, Taiwan) which has the following specifications:

- Temperature range: (-18-330 ºC (0-626 ºF))
- Response time: 500 mSec, 95% response.
- Spectral response: 8-14 µm.
- Distance to spot size: 8:1.

Used to measure the temperature increase during lasing procedure.

The teeth have been washed under tap water and by using a scalar the cementum and soft tissue debris were removed. In the geology department/college of science/university of Baghdad the teeth have been sectioned by an electrical saw (Lapidary trim saw, 500µm thickness blade, china) into slices. Each tooth was sectioned by making two cuts, one cut line at the cementoenamel junction and the other line was about 3mm apical to the first line as shown in Figure1.

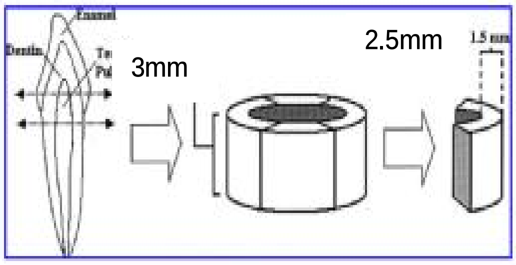


Fig. (1): Sample Preparation

Each slice was then divided into four parts. The thickness of each slice was made equal to 2.5mm. Each part was stored in 10% formalin solution at room temperature. The divided parts were distributed into four groups. Each part was placed in EDTA solution for thirty minutes to get rid from the smear layer. The divided parts have been placed in acrylic mold which was made by mixing equal amount of powder and liquid, until the mixture has reached to dough stage the divided tooth part was placed in the middle of the mold, in a manner that both the outer surface and the pulpal surface can be seen not covered by any acrylic material as shown in Figure 2.

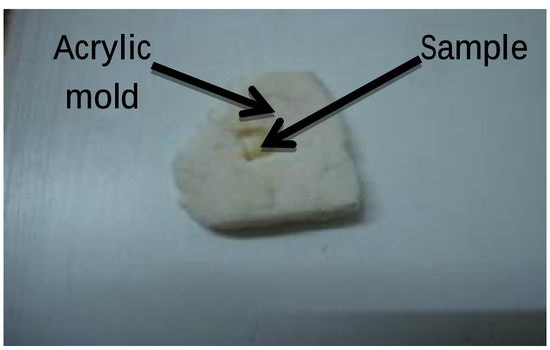


Fig. (2): the sample inside acrylic mold

each part has been placed in a separated plastic container and labeled form A-D, which represent the four groups that were going to be lased. So there were four groups:

***Group A(Control group)*:**This group represents the control group, so this group was not lased by laser; it was just examined under SEM to see the difference between the lased and non lased dentinal tubules.

Group B: This group has been lased by 80mj beam energy with a frequency of 6Hz for about 2 minutes. (energy density=40.8 j/cm²) This group consists of 10 parts.

Group C: This group has been lased by 100mj beam energy with a frequency of 6Hz for about 2 minutes. (energy density=51 j/cm²) This group consists of 10 parts.

Group D: This group has been lased by 120mj beam energy with a frequency of 6Hz for about 2 minutes. (energy density=61.2 j/cm²) This group consists of 10 parts.

Lasing method was done in non-contact manner with a laser spot size equal to 0.5 mm for 2 minutes in all groups. Lasing the samples were done by moving the sample in a scanning manner at one level from right to left then from left to right. An IR- Thermometer was placed behind the sample at a distance so that the whole irradiated sample area is detected. According to the user manual of the IR-Thermometer the ratio between the distances to the spot diameter equal to 8:1, so that IR-Thermometer was placed 20mm to get a spot diameter of 2.5mm which is sufficient to cover the sample. Temperature measurements were done by measuring the sample temperature before and after lasing, so the difference between the temperatures represents the amount of temperature increase after lasing.

Table (1). Shows the groups and different laser parameters

Groups	*Energy mJ*	*Repetition rate Hz*	*Energy density* J/cm²	*Exposure time (s)*
A	Control group (not lased)			
B	80	6 Hz	40.8	120
C	100	6 Hz	51	120
D	120	6 Hz	61.2	120

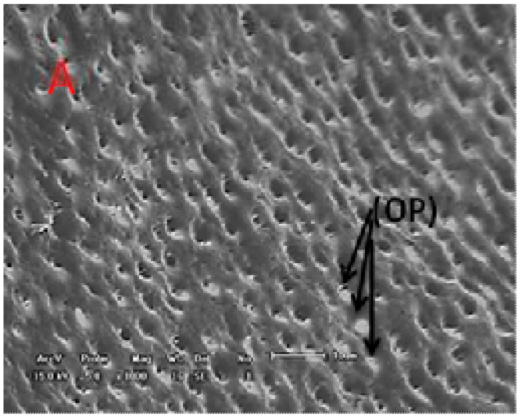
An examination of the samples was done in the royal scientific society/Amman/Jordon. The samples were placed in alcohol solution to get rid of any water that might be present with in the sample. After drying the samples with cotton the samples were then placed in a vacuum chamber to be finally coated by a conductive gold layer of thickness 25nm in sputtering unit Polaron E5100 (SEM Coating System, Inc., Polaron Equipment Ltd).

The samples then were placed over a round stage to be inserted into the chamber of the scanning electron microscopy (SEM) BS 340 (TESLA, Czech Republic). Three different magnifications have been taken for each group these were (X500, X1000, X2000), and the acceleration voltage for all the samples was 15kV.

Results

Evaluation was carried out using Scanning Electron Microscopy to assess the obliterating effect of pulsed Nd:YAG laser on human extracted teeth cervical dentinal tubule openings following sample preparation, comparing different energy densities in groups B ,C and D (Table 1). Initially Group A, which was not irradiated, was assessed with open dentinal tubules being observed (Figure 3).

Group A



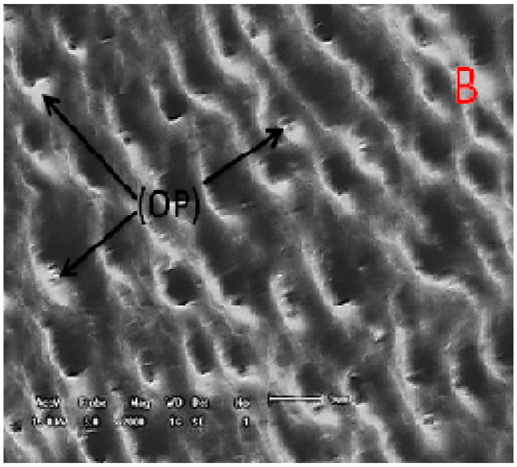
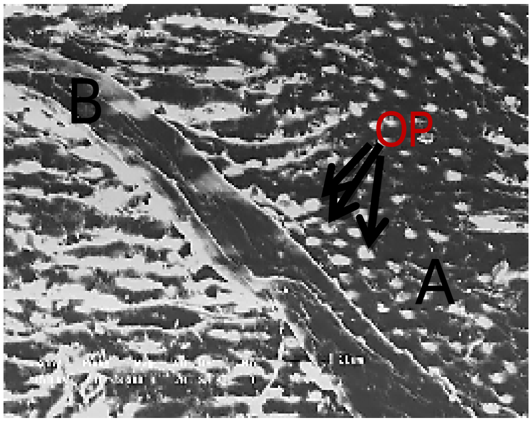


Fig. (3): SEM photographs of group A shows not-lased open dentinal tubules without any sign of smear layer also the odontoplastic process (OP) of some cells are evident . (A- with X1000, B- with X2000).

In groups B, C and D, dentinal tubule sealing was demonstrated by means of Nd:YAG laser irradiation with melting of dentin. There were morphological changes in irradiated dentin in groups B, C and D, with dentin fusion, recrystallization, and dentinal tubule obliteration. Fewer recrystallizations are obvious in group B is it compared to groups C and D and this is because of the higher energy densities that were used in groups C and D.

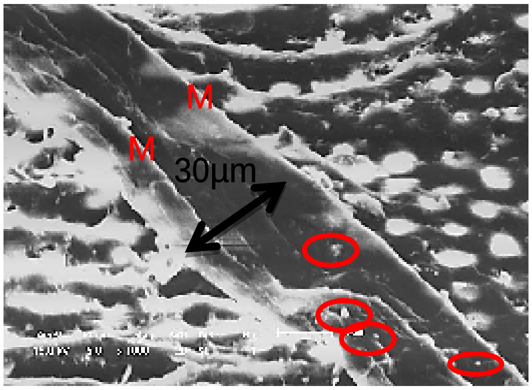
Sealing of dentinal tubules were more in group D while for groups B and C we have seen a partial obliteration in which large amount of dentinal tubules were still opened as compared to group D, as shown in Figures 4,5 and 6. A groove with a width of 30µm was created by laser beam in all the irradiated groups.

Group B

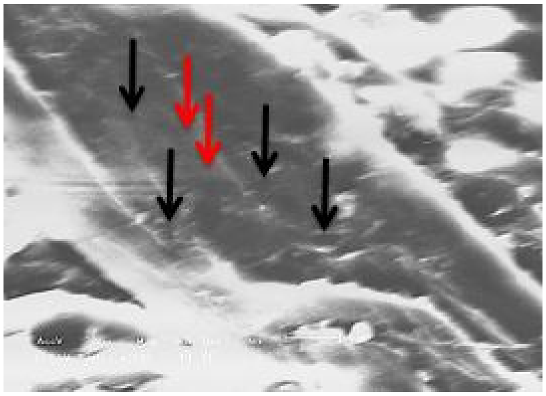


X500

A- Picture shows a large number of opened dentinal tubules with odontoplastic processes (OP). B- Large groove created by 80mj laser beam energy.



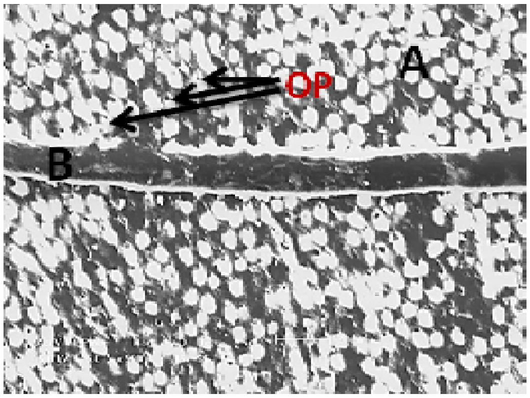
X1000 Shows partial closer of dentinal tubules with formation of resolidification materials (red ovals) with well-defined sharp margins (M) of the groove.



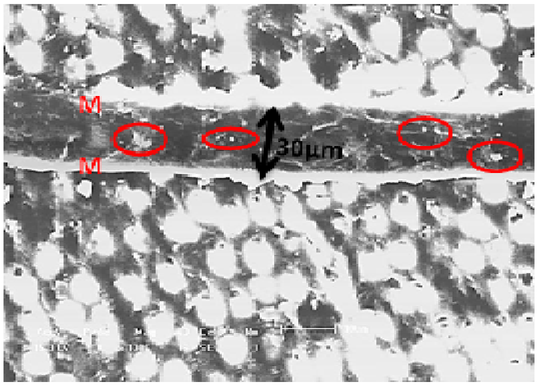
X2000 Large not sealed dentinal tubules (black arrows). Regular smooth melting surface of dentin (red arrows).

Fig. (4) : SEM pictures for group B samples with X500, X1000 and X2000 magnifications.

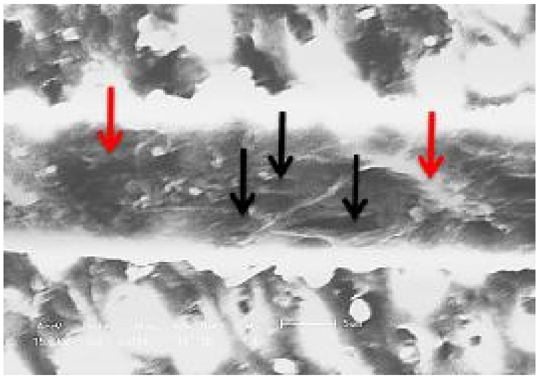
Group C



X500 A- Picture shows a large number of opened dentinal tubules with odontoplastic processes (OP). B- Large groove created by 100mj laser beam energy.



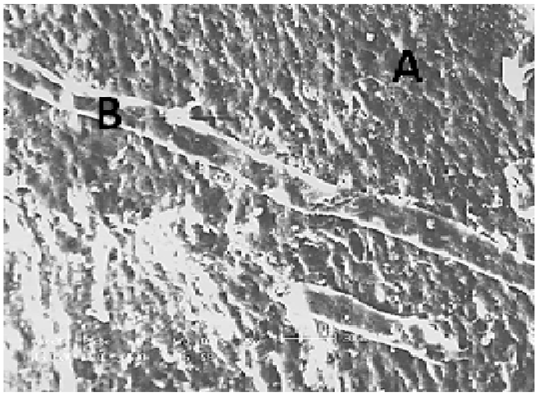
X1000 Shows partial closer of dentinal tubules but more than group B with formation of more resolidification materials (red ovals) with irregular margins (M) of the groove.



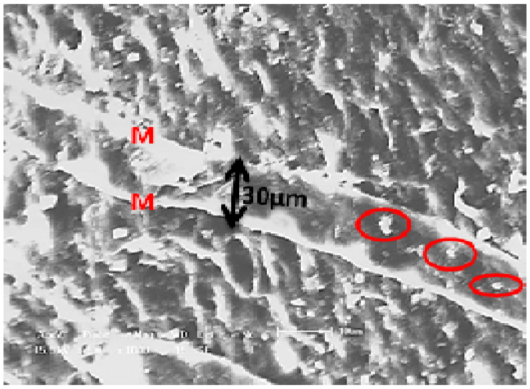
X2000 Large not sealed dentinal tubules (black arrows). Rough melting surface of dentin (redarrows).

Fig. (5): SEM pictures for group C samples with X500, X1000 and X2000 magnifications.

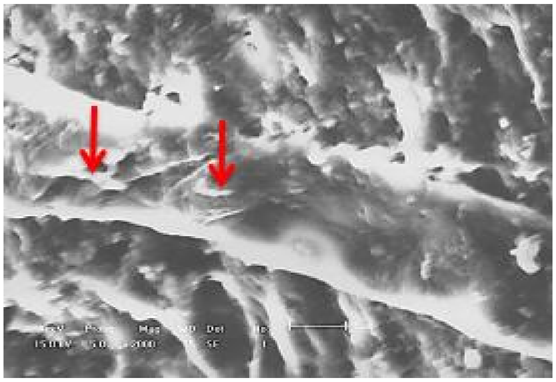
Group D



X500 A- Picture shows a large number of opened dentinal tubules. The odontoplastic processes are not obvious. B- Large groove created by 120mj laser beam energy.



X1000 Shows complete closer of dentinal tubules and more than groups B and C with formation of larger resolidification materials (red ovals) with irregular margins (M) of the groove.



X2000 Completely sealed dentinal tubules. Very rough melting surface of dentin (red arrows).

Fig. (6): SEM pictures for group D samples with X500, X1000 and X2000 magnifications.

In all of the above mentioned groups none of them showed cracking of the irradiated surface. The sealing depth of the lased dentin surface of all the groups were measured equal to 3-5µm in the middle of each groove. The temperature of the lased dentin surface also showed variation depending on the energy used in each group as in Table 2.

Table (2): Shows Temperature Increase in Each Group

Groups	Pulse energy (mJ)	Energy density(J/cm^2)	Temperature (^oC)
B	*80*	*40.8*	*1.5-1.8*
C	*100*	*51*	*2.0-2.4*
D	*120*	*61.22*	*2.9-3.3*

Discussion

The relation of DH to exposed dentinal tubules is widely accepted, and many treatment methods based on this principle have been proposed to alleviate dentinal hypersensitivity.

Nevertheless, achieving the full requirements suggested by (Grossman, 1935) is still a great challenge. Use of desensitizing agents such as 10% strontium chloride solution, 2% sodium fluoride solution, 40% formalin solution (Kishore., et al, 2002), and 3% potassium nitrate 0.2% sodium fluoride (Pereira., et al,2001) has yielded promising results. However, agents that blocked the dentinal tubules could not bind to the walls of dentinal tubules and thus were kept in place only by mechanical means. As a result of friction caused by daily tooth brushing and food chewing, these agents can be easily abraded and may eventually lose their occlusive effect. Therefore, the resiliency of these agents is not definitive, and their long-term effectiveness may decrease with time, like dentin adhesives (Panduric., et al, 2001) In vitro studies using the dentin disc model demonstrated that Bioglass or oxalate-containing products could occlude the dentinal tubules and may possibly possess therapeutic value. They claimed that Bioglass could release the calcium and phosphate ions in an aqueous environment and form a silica-rich layer. This reaction facilitates crystal growth and completely occludes the tubules (Gillam., et al, 2002). However, the clinically therapeutic effect of this material needs to be investigated further.

Compared with the physically occlusive effect of these materials, the photothermal effect of lasers exhibits potential for clinical applications and lures many researchers to study laser treatments.

This study shows that the Nd:YAG laser irradiation (group B,C and D) could melt the dentin and seal the dentinal tubules without creating surface cracks or altering pulpal vitality and this in good agreement with (Lan WH and Liu HC,1996).

Different studies have been done on the treatment of DH with laser temporal periods in millisecond and microsecond (long pulses) with no studies on nanosecond duration (short pulses).

During the photothermal interaction, molecules present in the tissue absorb photons, resulting in generation of heat, which is dissipated into the tissue. The absorbed energy depends on the molecule structure, laser wavelength, and energy and power densities on the sample surface. Since the tissue needs some time to propagate the heat, longer pulses will result in higher temperatures in deeper regions of the tissue, whereas for shorter pulses using the same average energy, higher temperatures are observed at the surface. According to Van Leeween thermal damage in tissue is always a temperature/time-dependent process, and the resultant confinement (stress or thermal) depends on the laser pulse duration and the tissue absorption coefficient. The use of longer pulses leads to longer interaction times, resulting in more evident thermal effects.

(McKenzie, 1993) observed that, during long exposure times, significant amounts of heat would diffuse out of the dentin surface during irradiation, reaching deeper structures; as a result, a larger volume of melted dentin and deeper resolidified structures could be seen after Nd:YAG laser irradiation. Thermal effects can also be associated with the relaxation time of the tissue. If all photons are delivered to the tissue in a pulse much shorter than the thermal relaxation time, damage due to temperature rise will be effectively confined in the surface area and the damage will be dependent on the magnitude of the pulse energy. However, if the irradiation time is much longer than the thermal relaxation time, comparatively little thermal damage is found within the original target, due to heat diffusion into the tissue (Anderson, et al., 1993).

By using large number of pulses per second results in lower energy per pulse and more pulse intervals, leading to a lower final temperature because the sample surface loses heat during the interval between two subsequent pulses. However, when the sample is submitted to a great number of thermal cycles, cracks in the surface can appear due to the induction of an initial temperature and stress distribution, leading to thermomechanical motions that produce tensile and shear stresses. When the local stress exceeds the local strength of the material, cavitations in soft tissue or micro-cracks in hard tissue can take place so that no cracks were observed in all the irradiated groups and this in good agreement with (Eduardo, et al, 2004).

In groups B and C there is a partial occlusion of the orifices of dentinal tubules because the energy density used during lasing was not sufficient to cause complete occlusion as in group D and this in good agreement with (Manoelita et al, 2004, Wan-Hong Lan et al, 2004 and Eduardo et al, 2004).

(Wan-Hong Lan et al, 2004 and Manoelita et al, 2004) measured the sealing depth of the Nd:YAG laser equal to 1-7µm which was in contrast to the findings of this present study in which the measured depth of sealing was ranging 3-5µm and this is because of different laser parameters were used in these studies.

The measured temperatures in all lased groups were found to be within the permissible limits for the vitality of the pulp tissue and this in a good agreement with (Zach and Cohen, 1965) in which they performed a study on pulp response to external application of heat; results have demonstrated that a few healthy pulps had not recovered from a temperature rise above 5.5°C.

Conclusion

In conclusion the Nd:YAG laser is effective in sealing dentinal tubules. The whole exposed dentin surface must be homogeneously irradiated to avoid areas left with open tubules. Laser penetration depth may vary from approximately 3 to 5 µm, using, respectively, 80mJ, 100mJ and 120mJ energy levels, with the other parameters being kept constant. The most effective pulse energy is 120mJ (61.22J/cm²) for 2 minutes with PRR equal to 6 Hz since it causes complete occlusion of the exposed dentinal tubules with no cracks of the surface and with heat generation within the permissible limits (5.5C°).

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معالجة مرضى بالأسنان الشديدة الحساسية باستخدام ليزر النديميوم ياك 1064 نانومتر: دراسة خارج الجسم

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الخلاصة اظهرت الدراسات للاسنان المقلوعة المصابة بفرط التحسس العاجي احتوائها على نبيبات عاجية عريضة بالمقارنة بالاسنان السليمة. العديد من الطرق والمواد المختلفة استخدمت في علاج فرط التحسس العاجي والتي اعتقد بكفائتها في احداث الغلق للنبيبات العاجية. الغرض من هذه الدراسة هو دراسة تاثير ليزر النيودميم-ياك على النبيبات العاجية المكشوفة للاسنان المقلوعة باستخدام المجهر الالكتروني الماسح. ثمانون شريحة بسمك 2.5 ملم من عشرين سنا مقطوعا قد قطعوا عند منطقة اتصال انسجة المينا والسمنت بواسطة منشار كهربائي. سنبلة ماسية استخدمت لازالة طبقة السمنت وذلك لكشف النبيبات العاجية.كل شريحة بعد ذلك قد قسمت الى اربعة ارباع متساوية وهذه الاقسام وزعوا الى اربعة مجموعات بصورة عشوائية(أ-ث). المجوعات من (ب-ث) قد شععوا لمدة دقيقتين باستخدام ليزر النيودميم-ياك بتردد 6هرتز بطاقات 100,80 و 120 ملي جول ,المجموعة (أ) استخدمت كمجموعة رقابة.الفحص باستخدام المجهر الالكتروني الماسح اظهر العديد من النبيبات العاجية المكشوفة للعينات الغير مشععة,كما اظهر انه باستخدام ليزر النيودميم-ياك بطاقة 80 ملي جول يمكن ان يحدث انصهارا في طبقة العاج وغلق جزئي للنبيبات العاجية المكشوفة وبدون تصدع في طبقة العاج.و لكن عند زيادة الطاقة الى 100 و 120 ملي جول ازداد عدد النبيبات العاجية المغلوقة بصورة ملحوضة. تولد الحرارة وجد بانه يحدث في جميع المجاميع ولكن مقدار الحرارة الناتجة هو بضمن الحرارة المسموح بها(5.5 درجة مئوية) والتي لا تحدث ضررا كبيرا على انسجة لب السن. تم قياس عمق الختم لليزر النيودميم-ياك و الذي وجد انه يتراوح بين 3-5 مايكرومتر للمجموعات من (ب-ث) وكان عرض الاخدود الناتج من الليزر مساوي ل30 مايكرومتر لجميع المجاميع. النتيجة النهائية من هذه الدراسة اثبتت انه باستخدام ليزر النيودميم-ياك بعرض نبضي مقدرا بالنانو جزءا من الثانية وبطول موجي مساويا ل1064 نانومتر وبطاقة 120 ملي جول للنبضة الواحدة وبتردد 6 هرتز لمدة دقيقتين (المجموعة ث) فعاليتها الكبيرة و الامنة في الختم التام للنبيبات العاجية المكشوفة للاسنان الحساسة وبدون زيادة كبيرة في الحرارة المتولدة اثناء المعلجة بالليزر والتي ان زادت عن 5.5 درجة مئوية ممكن ان تؤدي الى نتائج عكسية واحداث ضررا كبيرا في انسجة لب السن.